A Training Programme on Managing Science Class Interactions: its Impact on Teachers' Practices and on their Pupils' Achievement.

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Abstract: This research evaluates the impact of a training program on trainee physics and chemistry teachers, focusing on the way pupils' explanations are dealt with during teacher-pupil interaction. The population is composed of 10 teachers and 303 pupils, from which the experimental sample was taken (8 teachers and 172 pupils). The qualitative analysis of the recordings of the sessions shows that teachers, after training, are more ready to take pupils' productions into account, use a greater number of appropriate arguments, and are more frequently aware of pupils' misconceptions. A quantitative analysis of the achievement of pupils whose teachers followed the complete programme indicates that pupil outcomes improve. The conditions required for this training to be effective are also explored.

1. Introduction

Most research on training deals with how training procedures are devised and evaluated. Any validation of training procedures has to include both a theoretical and an empirical dimension. Theoretical validation is achieved through discussion of the procedure and its objectives with reference to the results of previous research, and also to different theoretical frameworks in the field of teaching, learning, and adult training. Empirical validation generally consists of an evaluation of the impact training has on the teachers. But this mode of evaluation is incomplete as it does not take pupil learning into account.

We take it as a principle that the main objective of any training is to encourage pupil learning by modifying teachers' practises. Thus, three levels of validation of a training program can be determined, depending on whether the entity evaluated is 1) teacher thinking 2) what the teacher and the pupils actually do in the classroom 3) pupil learning when their teachers have done this training.

The first level of empirical validation of training corresponds to the highlighting of the effects of training on teacher thinking, in other words, 'on the way in which teachers conceive, know and perceive their profession, their subject, and their activity…' (Tochon 2000: 130). The methods generally used to measure this are based on an analysis of what the teachers say about their practises. Several of these methods can be used together. For example we can cite the questionnaire and/or interview (e.g. Abd-El-Khalick & Akerson 2006, Désautels et al. 1993, Viennot 1997, Robardet 1998, Van driel et al. 2002, Lavonen et al. 2004), the analysis of the teacher's written observations, as in a log-book or a professional dissertation (e.g. Désautels & Larochelle 1993, Robardet 1999), or the analysis of the changes in knowledge used by the teachers during their training (Saint-Georges 1998, Fillon 2001, Boilevin et Dumas-Carré 2001, Author 1 2001a, Schaverien 2003, Bitain-Friedlander et al. 2004). The link between teacher thinking and teachers' practises is not assessed for this first level of validation. Training that does not impact teachers' actual practises, cannot impact pupil learning. For this reason, highlighting the effect of a training program on actual practises is a higher level of validation.

The second level of validation is thus reached when the effect of teacher training on actual practises can be highlighted (e.g. Bianchini et al. 2003, Boilevin & Dumas-Carré 2001, Fillon 2001, Luft 2001, Yip 2001, Lee 2004, BIQUA-Project[1]). In this instance, the method used is observation of teaching sessions. This observation may be direct, if the observer is in the classroom during the session, or indirect if the analysis is carried out by using a video or audio recording of the session. If it is taken into consideration that encouraging pupil learning is the aim of any training program, then this second level of validation is higher than the first. For if teachers' practises are changed, then so is pupil activity, and this can affect their learning. As teacher and pupil activity are closely linked, no distinction is made on this second level between research showing a change in teachers' practises, and research showing a change in pupil activity in the classroom. But if the analysis of teacher and pupil activity makes it possible to infer that learning is affected, this is still not pinpointed.

The third and final level of empirical validation of a training program shows what effect the training given to the teachers has on pupil learning. This last level of validation corresponds to what Guskey (2000), in his taxonomy, calls 'student learning outcomes'. This third level is higher than the previous level if we can consider that the ultimate goal of a training program is to encourage pupil learning through the training given to the teachers. Bibliographical research has been undertaken, but has not enabled the authors to find studies showing validation at level three in the field of science. Only the study carried out by Bartholemew et al. (2004) mentions such evaluation being carried out, but the authors do not give the results of this as the analysis of the data had not been completed when the article was published.

[1] BIQUA-Project: Retrieved Mai 21, 2007 from http://www.ipn.uni-kiel.de/projekte/biqua/

Some other research papers outside the field of science education have focused on evaluating the effect of a teacher training programme on pupils. (e.g. Veenman et al. 2002, Djalil & Lorin, 1989). The research presented in this article concerns the second and third level of validation as it provides the results of the evaluation on how training impacts teacher's practices and pupils' performances.

2. Theoretical framework for the training program proposed

The theoretical framework used for pupil learning is mainly socio-constructivism (Vygotski 1934, Doise et al. 1978, Bruner 1983, Perret-Clermont 1986, Author 2 & Martinot 2004). This theory holds that, in certain conditions, collective interactions enhance a child's individual development. Amongst the conditions given for this (Doise et al. 1978), we have focussed on the following: a socio-cognitive conflict is effective if a superior subject takes part in the interaction, and if the difference between the various subjects' reasoning and knowledge is not too great. If there is too great a gap between the knowledge used by the learner and that used by the teacher, "the inferior subject will not be able to explain what he finds difficult, and he will not be able to play any role in the negotiation and the final decision." (Doise et al. 1978, p. 252). This recalls Vygotski's idea of the Zone of Proximal Development (Vygotski, 1934).

The training course devised for this research chiefly aims at developing the teacher's ability to interact with pupils carrying out scientific inquiry based on the principles of a socio-constructivist approach. The training course is centred on the handling of pupils' productions. Indeed, when pupils undertake scientific inquiry, they make hypotheses, interpret observations, complete or validate models and devise experiments. For the pupils, these answers involve new knowledge, new experiments and new hypotheses. Thus, from the pupils' point of view, these answers can be defined as production activities. So the term 'production', rather than reply or explanation, has been chosen to describe the kind of answer the pupils produce during scientific inquiry.

These productions, which are peculiar to inquiry-based lessons, generate a period of interaction called a conclusion phase (Author 1, 2005). The conclusion phase is the moment in the interaction when a pupil's production is to be accepted or rejected. This is a tricky phase for teachers to manage. For they rapidly have to interpret pupils' productions, which are sometimes unexpected. They do not always manage to find the arguments which would enable them to accept or reject these productions. When faced with this difficulty, teachers sometimes avoid dealing with pupils' productions (Saint-Georges, 1996), or they use authoritative arguments which have little to do with scientific arguments (Author 1, 2001b).

A previous research study allowed two sorts of conclusion phase to be distinguished: evaluation and negotiation. The conclusion phase is called an evaluation phase if the production is assessed for its veracity. The teacher judges the pupil's answer to be correct or incorrect depending on whether or not it corresponds to the scientific knowledge he has. Scientific literature has already noted and described such interactions. (e.g., Edwards & Mercer 1987, Lemke 1990). In this case, it can be supposed that interaction does not contribute to the individual building of knowledge, as the knowledge is not built on the basis of what the pupil already knows. So the discussion between the pupil and the teacher moves away from scientific discussion as authoritative arguments are used. On the contrary, the conclusion phase is called a negotiation phase if the production is assessed for its validity, in other words, according to whether it is relevant to the question asked, and consistent with what is already known. This previously gained knowledge is that which is provisionally accepted by the teacher and the pupils involved in the interaction. The pupils and the teacher thus work together, in a perspective of co-construction. The validation of knowledge is founded on the principle that it is not contradictory with previously accepted knowledge (construction), and the pupils themselves take part in the development and validation of this knowledge (social construction). The examples given in part 4.1 of this article will allow us to illustrate the concept of the conclusion phase.

3. Hypotheses and method

On the basis of results in social psychology, we posit that a training program on the socio-constructivist approach to dealing with pupils' explanations in teacher-pupil interactions in science classes has a positive effect on pupil learning. This general hypothesis is built on the basis of two sub-hypotheses. The first considers that training in the socio-constructivist approach to dealing with pupils' explanations enables teachers to change their interactive practises. The second considers that a socio-constructivist mode of dealing with pupils' explanations in teacher-pupil interaction impacts pupil learning.

- Insert Fig. 1 -

In order to test sub-hypothesis 1, sessions taught by the teachers are recorded and then analysed qualitatively. To put it more clearly, this analysis compares the way teachers manage pupil productions in relation to the training they have received. In order to test the general hypothesis, we evaluate pupil learning and compare the results in relation to the training given to the teachers. In order to make this comparison, the mode of pupil evaluation must be the same. Moreover, for us to be able to attribute the effect measured to the management of pupil-teacher interaction, and not to the quality of the activities during the session, all the pupils must do the same activities. So, all the teachers will conduct the same teaching session. The session used in this quasi-experimentation is on the introduction of the particulate model.

3.1. The Session Used in the Quasi-Experimentation

The session implemented by the teachers and used for this experimentation is on the introduction of the particulate model in junior high school (Grades 7 and 8). It is based on another research project (Larcher et al., 1990) on pupils' misconceptions about matter, and ways to overcome these. The French Ministry of Education encourages teachers to teach this session by putting it in the program guidelines (MEN, 1997). This session is interesting as its relevance on both scientific and institutional levels has been acknowledged. Moreover, it is an introductory session on the particulate model, and so the performances measured for the pupils do not depend on previous sessions on the particulate model. The session lasts one hour. It comprises four successive tasks (see document given to the pupils at the start of the session, Appendix A). First of all, the pupils observe and describe the compression of nitrogen dioxide (brown gas) inside a blocked syringe. During the second task, they explain what phenomenon they have observed with the help of the particulate model (a particle cannot be cut, its dimensions stay the same, its mass stays the same and can't change shape). The third task consists in formalizing the links established between the register of the model and the phenomenological register (for instance: the gas is more compact = the particles are closer together), while the fourth task aims at adding two new properties to the seeds of the model: there is empty space between the particles; the number of particles characterizes the quantity of matter.

3.2. The Trainee Teachers' Training Program

The aim of this program is to prepare the trainee teachers for dealing with pupils' productions in scientific inquiry. The training program is composed of three sessions (S1, S2, S3).

The first session lasts three hours, and deals with a discussion of the session on the introduction of the particulate model. The second training session is also three hours' long, and deals with the handling of pupil-teacher interactions in a science class. Finally the third session is six hours' long. It consists first in a computer simulation of the way of dealing with pupils' explanations during the session on the particulate model, and then, in analysing the decisions made during the simulation.

Training Session S1: An Analysis of the Session Introducing the Particulate Model

The first training session deals with an analysis of the epistemic and pedagogical stakes in the teaching session on the particulate model. The program guidelines presenting this session (MEN 1997), the document given to the pupils at the beginning of the session (Appendix A) and an article by the authors of this session (Larcher et al.,1990) are analysed with a view to determining: a) the pupils' misconceptions which are dealt with during the session (gases have no mass, the quantity of matter is proportionate to its volume, there is no void in matter, there is a transfer of the macroscopic properties of matter to its microscopic properties); b) the properties of the model which are also dealt with in this session (the model is hypothetical, explanatory, predictive, and may evolve; it has its own coherence, and a field of validity); c) the contents that are tackled in this session (e.g. the primary properties of the particulate model) and the contents which are not tackled (e.g. particle motion).

Training Session S2: Dealing with pupils' explanations During Scientific Inquiry

The second training session lasts three hours. It deals with conclusion phases, the point in teacher-pupil interaction when a pupil's production is to be accepted or rejected. First of all, the trainees are asked to write down how they think they would react to different pupils' productions. These productions are real ones coming from recordings of sessions on optics, radioactivity, and static electricity. Around twenty such productions are processed by the trainees. Then, the tutor presents the different kinds of conclusion phases that emerge from the session, and the beliefs they convey. Two kinds of conclusion phase are distinguishable: the negotiation phase and the evaluation phase (cf. theoretical framework).

After this theoretical presentation, the trainees once more imagine how they would react in the same situations as those presented to them at the beginning of the session. The way they think they would interact during conclusion phases is compared and discussed in the light of the theoretical input they are given beforehand on dealing with pupils' explanations. The trainees are asked to interpret the origin of each pupil's production, by explaining the way the pupil reasons and what knowledge they makes use of. What is at stake in this interpretation phase is the understanding of the origin of the pupil's production. If the production has not been validated during the conclusion phase, then this interpretation phase may be an opportunity to question the pupil's reasoning and the knowledge he made use of.

Training Session S3: Contextualizing Knowledge Acquired During S1 and S2 Through an Analysis of Simulation of the Management of the Session Introducing the Particulate Model

The third training session lasts six hours altogether and is in two parts of equal length. First of all, the teachers use a computer program to carry out a simulation of the management of the particulate model session. Secondly, the actions simulated by the teachers are compared with each other, and analysed pedagogically, epistemically and/or scientifically. Before a more precise description is given of the simulation program, and how it is used, here is a brief presentation of its design.

The computer program (http://www.the address of author 1’s website.htm) was designed using five recordings of sessions taught on the particulate model (Larcher et al. 1990). These five sessions were recorded and transcribed. The pupils’ written productions during the sessions were also collected. The pedagogical situations encountered by the teachers during these five sessions were put into the program. These situations are mainly those in which the pupils present and account for their productions in response to the tasks they are asked to carry out. The professional knowledge used in this session is different from that in the second training session (S2) in that it is contextualized professional knowledge concerning the session which will actually be taught. The teacher is asked by the program to accept or reject each pupil’s production and to explain their decision to the pupils. The program gives the teacher the possibility of asking a virtual pupil to account for his production. They can also ask other pupils to accept or reject a production; they can explain to a pupil the way they interpret the origin of his/her production; they can give more detailed instructions (define the number of particles to draw, choose just one symbol to represent the particles, or interpret the inter-particulate space). The teacher can also access a virtual board where he can write or rub out whatever he wants whenever he wants. All in all, 53 pupil productions were processed in this way. Every action carried out by the teacher is saved, which makes it possible to retrace the progression of the simulation afterwards. In order to make the teachers account for and reflect on the reasons for their choices, they are put in pairs in front of one computer during the simulation.

The second period of this training session is devoted to analysing the simulation. The simulation program is used by the professor with all the trainee teachers, by means of a video-projector. Each teacher has a written document with all the decisions they made during the simulation. These decisions are compared with each other, and the teachers justify them in pedagogical, epistemic and scientific terms. For this third training activity (S3) the knowledge the teacher initially presented in the first and second sessions is now contextualized. For each production, they think up, exchange and compare arguments for accepting or rejecting these productions, then they interpret the origin of these productions. The knowledge used is closely linked to the teaching situation. Analysing the simulated activity in this way allows us to work on the epistemic and pedagogical standpoints which have been pinpointed as potentially problematic for physics and chemistry teachers (Porlan Ariza et al., 1998).

3.3. Hypotheses

For this training programs' teachers did audio recordings of the sessions they taught. The organization of the programme made it possible to collect the evaluations of pupils (P1, P2, P3) whose teachers respectively did the S1, S1+S2, S1+S2+S3 training sessions. The three training sessions were built so as to be complementary. The objective of Session S3 is to teach teachers how to manage pupil-teacher interactions in a session on the particulate model. Thus, S3 is complementary to S2 and S1 which respectively tackle general and de-contextualized interaction management (S2), and the particulate model session (S1). This study does not claim to show that one training session is more effective than another. The objective is to evaluate the cumulative effect of each training session on pupil learning. This objective will lead us to compare on the one hand how teachers having followed either S1, S1 + S2, or S1 + S2 + S3 manage pupil productions during interaction, and, on the other hand, to compare the achievements of pupils whose teachers did either S1, or S1 + S2, or S1 + S2 + S3.

The training given the teachers should lead them to take pupil productions into account more systematically, to use arguments of validity (no contradiction with what is already known) and not authority, and to pick out the misconceptions hidden in the pupils' productions. Managing productions in this ways encourages pupils to link up different forms of knowledge (linking available knowledge, and the knowledge produced during the inquiry). This link is based on principles of non-contradiction, validity, and construction, and is woven when the pupils consider the validity of their productions. Managing productions in this way encourages pupils to link knowledge and to take part in validating productions as it makes use of knowledge the pupils already have. Thus, the collective construction of knowledge should be favourable to individual construction of knowledge (sub-hypothesis 2). The only 'variable' used directly in this research is 'training'. Sub-hypothesis 2 is therefore not tested directly, but its validity is inferred from the results obtained for testing sub-hypothesis 1, and the general hypothesis. The general hypothesis, according to which a training program on the socio-constructivist approach to dealing with pupils' explanations in teacher-pupil interactions in science classes has a positive effect on pupil learning leads us to anticipate that the results obtained by the pupils can be classified in the following hierarchical pattern: P3 > P2 > P1.

3.4. Conditions in Which Data Were Collected

These three training sessions (S1, S2, S3) are given three years running to three different cohorts of second year Physics and Chemistry trainees at the Institut Universitaire de Formation des Maîtres (I.U.F.M.). At the start of the session, the teachers are informed that they will be asked to take part in a collection of data for a research study aimed at evaluating the way training impacts their practices and their pupils' performances. The teachers are told that taking part in this collection of data is optional and anonymous. The teachers still have pedagogical freedom, as they can choose whether or not they will teach this session in the form that is suggested, depending on what they know of their own pupils' abilities. At the end of each session, the professor asks the trainees if they would be interested in teaching the session on the particulate model to the pupils in their class. For those who decide to take part in the collection of data, the time at which they teach the session depends mainly on their long-term teaching plan, in other words, on the order in which they will be tackling the different themes on the syllabus. Thus, the group which the trainees come from (S1, S1 + S2, or S1 + S2 + S3) is merely a question of chance.

The volunteers take two sealed envelopes. The first contains, for each pupil, a test (an open question) which is to determine the level of knowledge they have on the particulate model, and also a photocopy of a document presenting the four activities in the session on the particulate model (see Appendix A). The second envelope contains a test questionnaire (see Appendix B) which is to indicate the level they attain after the session has been taught. So as to harmonize the way in which the test is taken and the data collected, the instructions for the test are written on the envelopes. The teachers are asked not to open the envelope before the test questionnaire, so that the evaluation does not impact the teacher's practises.

3.5. The Teachers' Experimental Population

The eight trainees taking part in the collection of data are all trainee physics and chemistry teachers in their second and final year of training at the IUFM. They all teach in different junior high schools, where each of them is totally in charge of several classes for the whole school year. Each of them passed their secondary teaching exams the year before taking part in the research project. These exams guarantee that all the teachers have roughly the same mastery of scientific knowledge. Moreover, they all have at least a university degree. The way the teachers are divided up into groups T1 (2 teachers who did S1), T2 (2 teachers who did S1+S2), T3 (4 teachers who did S1+S2+S3) depends solely on the order in which the teachers decided to tackle the different themes on the syllabus.

3.6. The Measurement Carried out with the Pupils

The test is a questionnaire (appendix B) composed of 15 questions. The aim of the questionnaire is to assess the understanding and integration of beliefs related to the particulate model (gases have mass, the volume of matter is not always proportionate to the quantity, there is void in matter, the macroscopic properties of gases differ from their microscopic properties). These beliefs are quite different from those generally held by children of this age (Larcher et al., 1990). So this test attempts to evaluate the level of conceptual change reached by the pupils.

Several items in this questionnaire are easy to interpret (e.g. Gases have mass; A gas particle can get bigger), whereas others are more complex (e.g. There is air between the gas particles). This last item is considered to be inaccurate as, in the context of this research, pupils have only worked with pure gas up till now. Moreover, in activity 2, they had to differentiate between the macroscopic description of gas (e.g. just one gas) and the microscopic description of it (e.g. just one kind of particle). The item 'There is air between the gas particles', mixes these two levels of description as the word ‘air’ is on a macroscopic level, and ‘gas particle’ is on a microscopic level. As the pupils’ confusion of the macroscopic and the microscopic worlds led to numerous errors, it needs to be worked on in the science class, and evaluated. Some pupils, who reject the idea that there is a void in matter, think that the inter-particulate space is not empty, but contains air. In this case, the item is considered to be inaccurate, as the main aim of this session is to get pupils to accept the idea that there is void between the particles. However, beyond the context of this session, the item 'There is air between the gas particles', could be considered to be accurate on two conditions: that the gas in question is a mixture of gases and no longer a pure gas; and that the evaluator accepts the mixture of a macroscopic (air) and microscopic (gas particles) description of matter in the same sentence. So, in order to evaluate the reliability of the questionnaire, 18 trainees in physics and chemistry, who were not part of the experimental population, and who served as independent judges, drew up a model for correcting each of the questions asked. This variable had a reliability coefficient (Cronbach’s alpha) of .78. It is apparent that there is a high level of agreement between these judges. As we did not wish our research to disturb the teacher’s usual classwork too much, the questionnaire was given in a summative evaluation (in test conditions) and was identical for all the pupils. It allowed the teacher to give the pupils a mark.

It would have been easier for the evaluation-test to be the same, or almost the same as the first test so as to measure what the pupils had learnt. But it did not seem to be appropriate to ask questions about the properties of gas particles before the session, when the pupils do not even know yet that a gas can be represented in particles. In order to get round this methodological restriction, we checked the homogeneity of our pupil samples.

3.7. The Experimental Pupil Population

All in all, 303 pupils were involved in the collection of data. The sampling of pupils in groups P1, P2, P3 is random as it depends on the classes given to the teachers at the start of the school year and on the order in which the teachers have decided to tackle the different themes on the syllabus.

The pupils’ standards before the experimentation were tested through two indicators. At the beginning of each learning sessions, all the pupils provide a written answer to the open-ended question: ‘What do you know about gases?’. The analysis of the answers reveals a total absence of the terms ‘particle’, ‘molecule’ and ‘void’, whatever the classes and the composition of the observation groups (P1, P2, P3). At this stage of their schooling (Grade 7, i.e. 12-13 year-old children), pupils should not have studied this model. The aim of this question is to make sure of this. Consequently, we can accept that all the groups have an equivalent level as far as their knowledge of the particulate model prior to each learning session is concerned.

As the pupils all came from different schools, another methodological precaution consisted in comparing the overall academic standards of the pupils involved. So as to assess the pupils' general level at the outset, we calculated the average mark obtained in the different sections of the national standard achievement maths tests for each pupil. This scientific achievement indicator is the only basic institutional indicator available in France before the age of 13. However as some difficulties were encountered in trying to get the results of the national evaluations in some schools, this study deals with the 172 pupils for whom we have all the necessary indicators. The statistical tests – variance analysis - carried out from these averages reveal no significant difference between the various scores for the three groups of subjects: P1 (N=40, M=64.29, SD=16.73) ; P2 (N=44, M=73.96, SD=14.3) ; P3 (N=88; M=67.76, SD=15.87). Thus, these results allow us to state that the groups studied with these two indicators are equivalent and allow us to put our hypothesis to the test. For two out of the ten teachers, we did not collect any data concerning their pupils' basic academic level. Thus the teacher population used in the statistical analysis is N=8. While the pre-test gives us information about the pupils' standard in physics, these data give information about the pupils' overall academic standard.

4. Results

Two kinds of data, both qualitative and quantitative, were collected. The recordings of sessions the teachers gave the pupils are qualitative data; the pupils' achievements are quantitative data.

4.1. Presentation of the first part of the results: the impact of the training program on dealing with pupils' explanations during class interaction

In order to ascertain how the training program alters the teachers' practices while they are actually teaching, the recordings of the sessions are analysed. As all the teachers taught the same session, some pupils' productions during these sessions are also the same. So it is possible to compare the different ways in which the same production is managed by the different teachers. The choice of the extracts is determined by comparing the management of the same production by teachers having done S1, S1 + S2, and S1 + S2 + S3. In this qualitative analysis, we try to see whether the pupils' productions are taken into account, the arguments used are arguments of validity or authority, and whether the teacher notices and explains the pupils' errors in reasoning, and their misconceptions. Using these criteria to analyse the data provides us with indicators which allow us to determine if the way of dealing with pupils' explanations bears similarities with socio-constructivist management. The exchanges have been coded as follows: XEY means utterance X in Extract Y in the session transcript. The letter P is added if it is a pupil (XEYP), and if it is a teacher, the letter T is added (XEYT).

How do teachers deal with the productions concerning the quantity of gas?

The session on the particulate model begins with an observation activity during which pupils are asked to observe the compression of the brown gas in a syringe and to write what has changed, and what has not changed for the syringe and the gas in a table. In the column 'what hasn't changed', the pupils often put 'the quantity of gas'. Indeed, as the syringe is hermetically closed, the brown gas can't have got out, and no gas can have got in. So, the quantity of gas has not changed. But some pupils mix up the volume and the quantity of gas.

Indeed, in the majority of situations in everyday life, the volume and the quantity of a matter are proportional, and the two concepts are not differentiated. This situation in which gas is compressed is one of the first phenomena encountered by pupils in which the volume of matter changes without the quantity changing too. The analysis of extracts from the sessions which concern the management of the production ‘the quantity of gas has not changed’ allows us to find differences in the management of this production between teachers having done S1, S1+S2, or S1+S2+S3.

In the first extract, a teacher who only did S1, accepts the production ‘the quantity of gas’. However, the pupils seem to be somewhat confused about the concepts of quantity, content, and volume. The term ‘content’ is not very clear. It refers more to the idea of the volume of a receptacle, whereas the pupil (2E1P) seems rather to use it to mean quantity, as he answers ‘the content is still the same’. This confusion is not cleared up, as the teacher implies that content and quantity are similar (9E1T). Finally, there is no argument given for this production being accepted, and the difference between content and quantity is not made clear. By acting in this way, the teacher does not make it any easier for the pupils to make a distinction between these concepts. As the teacher does not justify his acceptance of the production, he does not link the production with previously acquired knowledge, which, in socio-constructivist theory, does not contribute to the construction of knowledge.

Extract 1 (teacher having done S1)

1E1 Teacher:	Go ahead Camille.
2E1 Pupil:	The gas content is still the same.
3E1 Teacher:	Oh.
4E1 Pupil:	It does not have a particular shape.

5E1 Teacher: The gas content is still the same. So it hasn't changed. I saw Antoine at the back had put something else.

6E1 Pupil: The volume.

7E1 Teacher: What have you put in 'what hasn't changed'?

8E1 Pupil: The quantity of gas

9E1 Teacher: The quantity of gas, the content, so yes, the quantity of gas (the teacher writes 'the quantity of gas' on the board).

10E1 Pupil: And the volume.

11E1 Teacher: Yes, the volume, that's what I wanted.

In the second extract, a teacher having done S1 and S2 will also accept the production asserting that the quantity of gas has not changed. In this case, an argument is given for this acceptance. A pupil gives the argument (4E2P) when asked to by the teacher (3E2T). The argument used here consists in saying no gas has gone into or come out of the syringe. The explanation is related to the phenomenon which has already been observed. The knowledge used for the argument comes with reference to what is already known (an observed phenomenon). This allows us to say that it is co-built knowledge.

Extract 2 (teacher having done S1+S2)

1E2 Teacher: What do you mean by the same quantity of gas? Can I add any more there?

2E2 Pupil: No.

3E2 Teacher: Why not?

4E2 Pupil: Because none goes in or comes out.

In the third extract, the teacher having done S1 + S2 + S3, also accepts the production ‘the quantity has changed’. When the pupil gives a rather confused answer ‘it (the volume) is the same, but it’s squashed in the syringe’, the teacher will first try to differentiate quantity and volume (3E3T). The written record which he will dictate to the pupils clearly opposes the quantity and the volume, which may help the pupils to make a distinction between the two concepts: ‘the volume has changed, but the quantity hasn’t’ (10E3T). Various arguments are used to accept this production: no gas has leaked out (8E3P, 10E3T), the syringe was closed (11E3T), it was hermetic (11E3T). Moreover, the teacher notices and explains the pupils’ misconceptions (the confusion between quantity and volume). Even if the interaction still takes an 'Initiation-Response-Feedback/Evaluation' (IRF) form (Sinclair and Coulthard, 1975), the contents of the interaction are different. The teacher who did the three sessions (S1 + S2 + S3) gives various arguments for accepting the pupils’ answers (8E3P, 10E3T, 11E3T). However this is not the case with the teacher who only did S1. The teacher who did the three sessions opposes the concepts of quantity and volume (3E3T, 10E3T), unlike the teacher who did S1 + S2.

Extract 3 (teacher having done S1+S2+S3)

1E3 Teacher:	I saw someone had put something about the volume? What has happened to the volume.
2E3 Pupil:	It’s still the same, but it’s squashed up in the syringe, whereas at the beginning it had more room.
3E3 Teacher:	Well in fact, you may be mixing up two things. You may be mixing up the volume, and what is in it. The volume is inside the cylinder. So, has the volume changed?
4E3 Pupil:	Yes.

5E3 Teacher: Has the amount of gas inside changed?

6E3 Pupil: No it hasn't.

7E3 Teacher: So what has not changed is…For example, has any gas leaked out?

8E3 Pupil: No.

9E3 Teacher: No, it hasn't as I closed it tightly and the piston is hermetic.

…

10E3 Teacher: Write down, the volume has changed, but the quantity of gas hasn't, because none has leaked out, I pressed down hard so that it would be hermetic.

…

11E3 Teacher: The syringe was closed, there is no more gas afterwards, no less either, than before. The quantity hasn't changed, has it?

How do the teachers manage the productions about the syringe changing shape?

During the first activity in the session, some pupils answer that the syringe has changed, that its shape has changed, that it has puffed up because of the pressure. Although the observation of the syringe gives no evidence to conclude that it has changed shape, the pupils think they have seen it change. This can be explained by the use of false reasoning according to which quantity is always proportional to volume. Indeed, as the quantity of gas in the syringe has not changed, as the piston has been pushed in, the only way to reconcile these observations with the idea that 'the same quantity means the same volume' is to say that the syringe has puffed up, even if no pupil has actually been able to observe this phenomenon.

In extract 4, a teacher who did S1 does not tackle this production. He waits for the pupils to mention the pressure of the gas or the colour to set the pupils off on a different subject (the piston cannot be pushed right in). As the teacher does not reject this production, he may lead some pupils to think it is correct. He might leave the pupils with inaccurate knowledge, and even let this knowledge be picked up by other pupils who hear the answer. If the pupils think the syringe has puffed up, they will not be aware of one of the major goals of the session, which consists in accepting the idea that the same quantity of gas can occupy a different volume, which also allows the introduction of the existence of void in matter.

Extract 4 (teacher having done S1)

1E4 Teacher:	The syringe puffed up. Did it? Did it puff up between the first situation and the second.
2E4 Pupil:	Yes, it’s bigger now.
3E4 Pupil:	When the colour changed, I think it’s the pressure, the denser the pressure, the darker the colour.
4E4 Teacher:	OK, so we’ve mentioned pressure and colour, what else?
5E4 Pupil:	You can’t push the piston right in.
6E 4 Teacher:	So you can’t push the piston right in, OK.

However, two teachers who respectively did S1+S2 and S1+S2+S3 will take this kind of production into account. In comparison with the teacher who only did S1, these two teachers have been made aware of the importance of accepting or rejecting pupils’ productions during interaction. They do not ignore this production but take it into account. It can be noted that the teacher who did S1+S2+S3 (extract 6) insists more than the one who did S1+S2 (extract 5) to make sure the pupils agree with what has been said. These two conclusion phases (extracts 5 and 6) are considered as negotiation phases, as the experiment on the compression of brown gas showed that the syringe didn’t change, puff up or change shape. Thus, there is a contradiction between saying the syringe has changed shape or puffed up and the phenomenon which had been observed previous to this. What is more, the syringe not being distorted or changed is an important experimental fact for the pupils' conceptual change. Indeed, it goes against the pupils' misconception when they think that the volume of matter is proportionate to its quantity.

Extract 5 (teacher having done S1+S2)

1E5 Pupil: The syringe hasn't changed, except for the black knob.

2E5 Teacher: No, it hasn't, you're right, the piston is pushed a bit further in.

Extract 6 (teacher having done S1+S2+S3)

1E6 Teacher: What hasn't changed?

2E6 Pupil: The shape of the syringe

3E6 Teacher: Yes, the shape of the syringe. So the syringe does not change shape when I compress it.

…

4E6 Teacher: So the colour, so what has changed for the syringe is that I have compressed it, I pressed down on it. You can write that we pressed down on the syringe. And then, did it change shape?

5E6 Pupil: No.

6E6 Teacher: No.

How do the teachers manage the production '*there's air between the particles*'*?*

The last example presented here concerns the question of the void between the particles. For a non-scientific reader to understand the following analysis, they need to know that a pure gas can be compressed because there is empty space between the particles of matter. The pupils find it very hard to accept the idea that there is a void between the particles. Some say there is air between the particles, others say there are other particles, but very few accept the idea of a void. A teacher who only did S1 rejects the idea there is air between the particles, using the following arguments: if there was air between the particles, it would have been represented (drawn) in the syringes in Activity 2, and as they were not represented, then there isn't any air. In this instance, the teacher turns the argument round, by supposing that the representation of the model is proof of the fact there is no air between the particles (the particles don't exist as they have not been represented).

A teacher who did S1 + S2 attempts to invalidate the idea that there is air between gas particles by taking the case of air and reasoning as follows: air is a gas itself, so it is formed of particles, and between air particles there cannot be other air particles. But the pupils are impervious to this argument, as they again reply that there is air, gas, oxygen between the particles. The teacher then returns to a correct answer given by a pupil who said that there was a void, and rejects the answer that there is air between the particles. So he eventually uses an argument from authority, as he hasn't found any arguments for validity adapted to the situation and understandable by the pupils, which would enable him to invalidate the presence of air between gas particles.

A teacher who did S1+S2+S3 rejects the idea that there could be air between the particles. His argument for this rejection is that if the space had been filled with air particles, then the syringe could not have been compressed. In this case, the teacher refers to a phenomenon (brown gas compression) that the pupils know. He shows the contradiction between the pupil's production (there is air between particles) and the knowledge the pupils already have: gas is compressible (observed phenomenon); particles are not (see appendix A, Activity 2, P2:

a particle keeps the same size); air is a gas. This allows us to say that this conclusion phase is a negotiation phase. A bit later on, the teacher defines void as an absence of particles.

Discussion of the first part of the results

In conclusion, the qualitative analysis of the recordings of teaching sessions shows differences in the management of productions between teachers who did S1, S1 + S2, S1 + S2 + S3. These differences may be characterized as follows: the teachers who only did S1 ignore some pupils' productions, not taking them into account. When the teacher has to judge pupils' productions, he does not systematically give arguments for accepting or rejecting productions. When he does use arguments, they are not necessarily well-adapted to the pupils' productions. The teachers are not aware, or only slightly aware, of underlying misconceptions in pupils' productions.

The teachers who did S1 + S2 have been made aware of the need to take pupils' productions into account during interaction, and they do not ignore any productions. They try to provide arguments for accepting or rejecting pupils' productions, but they do not always find suitable arguments. They do not always see the learning difficulties, in particular the misconceptions the pupils make use of in their productions. Indeed, as the pupils' beliefs are frequently implicit, the teacher has to interpret the pupils' productions in order to infer what misconceptions lie behind these productions. The teacher can therefore take a production into account (by accepting it or turning it down) without necessarily determining the misconception lying behind it, or making it explicit.

The analysis of the extracts we have presented above seems to indicate that the teachers who did S1 + S2 + S3 take into account all the pupils' productions during a session, they have one or several suitable arguments to justify their accepting or rejecting pupils' productions, and they are able to spot pupils' learning difficulties through their analysis and interpretation of the pupils' productions.

This analysis provides qualitative evidence that the training program alters teachers' practices, and leads them to take more account of pupils' productions during interaction. The socio-constructivist approach to dealing with pupils' explanations which was developed during the training program should have a favourable impact on pupil learning.

4.2. Presentation of the second part of the results: comparison of the effects of the teachers' training on their pupils' results

The statistical analysis of this average performance reveals results which are in part consistent with our forecasts (table 1). Indeed, as predicted in the first part of our hypothesis, a variance analysis brings out an effect of the training situation ($F(2, 171) = 12{,}952$, $p<.0001$, $\eta^2 =.13$) and a test of linear contrast confirms that is in the way we had expected ($F(1,171) = 19{,}135$, $p<.0001$).

- Insert Table 1 -

In spite of the training having a significant effect, we wanted to check whether this effect could not be accounted for by the way the pupils having a low or high basic academic level are divided up in each teacher's classes. In some classes, the high- achieving pupils represented between 35.5 and 100% of the total number of pupils in the class for which we had all the data. So we classified the teachers depending on this proportion, going from the lowest to the highest (fig. 2). In this graph, each percentage refers to each specific teacher. If the status of having a high or low academic standard impacts the pupil's mark in the evaluation, regardless of the training the teacher has received, it is then to be expected that the class with the lowest number of high achievers will have the lowest class average, whereas the highest average will be in the class having only pupils with a high academic standard. What is more, we should be able to observe a linear increase in these averages, in correlation with the proportion of those with a high academic standard. But the graph of these averages does not make it possible to confirm this hypothesis.

- Insert Fig. 2 -

Further analyses also showed that the effect is exactly the same for all the pupils, whatever their basic academic standard (table 2). It reveals the same significant differences in the performances depending on the basic academic level of the pupils ($F(2,77) = 6.823$, $p=.002$; $F(2,93) = 7.610$, $p=.001$) and a linear increase in the achievements which tallies with our hypotheses ($F(1,77) = 11.232$, $p=.001$; $F(1,93) = 6.023$, $p=.016$). It would thus seem that that no pupil effect can account for the progression in achievement better than the training itself can.

- Insert Table 2 -

We also considered whether there was a teacher effect. Although the teachers share a large number of characteristics, there may still be intrinsic differences between them which may impact their pupils' achievements. If there is such an effect, it is to be expected that, in spite of an overall effect of the training, teachers will obtain very variable results on each level of the training programme. So a variance analysis was carried out in order for us to be able to compare the average scores obtained in the test in each class for each of the three levels of training. For the S1 session, no significant difference was found between the two teachers ($F(1,39) = 3{,}116$, $p = .086$). However, for the S1+S2 level, one of the teacher's pupils get significantly better results in the test than the other teacher's ($F(1, 43) = 4{,}645$, $p = .037$). Finally, the averages obtained by the pupils of the 4 teachers who did S1 + S2 + S3 are very significantly different ($F(3, 87) = 12{,}952$, $p<.0001$). So this would confirm the hypothesis that there is a teacher effect on pupils' performances in the test, over and above the effect of the training programme.

If we take into account the quasi-experimental nature of this study, and above all the small number of teachers (only 8), it is impossible to carry out multi-level hierarchical analyses which would make it possible to quantify this teacher effect by integrating the characteristics of the training, the teachers and the pupils in the same analytic model. Nevertheless, this initial analysis does allow us to show that this training programme is indeed effective. Although its effect probably varies according to each teacher's intrinsic characteristics, the programme allows pupils to progress whatever their basic academic level may be. These initial results will need to be confirmed through research using larger samples.

Discussion of the second part of the results

The result shows that training teachers in science class interactions positively impacts pupil achievement. At the end of S1, the teachers have not yet received any training in dealing with pupils' explanations. All the training in interactions is covered in the association of S2 + S3. Session S2 tackles the issue of interaction management in a general and de-contextualized way. Session S3 tackles the issue of interaction management in a contextualized way. The results obtained make it possible to conclude that 1) the training given teachers on interaction (S2 + S3) has a positive impact on their pupils (P3>P1) and that 2) contextualized training in association with general training on interaction (S3 + S2) has a greater effect on pupil achievement (P3>P2) than when teachers only have general and de-contextualized training (S2). We cannot conclude here that the contextualized training session is more effective than the general and de-contextualized session. However, we can conclude that the S3 training session in association with the S2 session is more effective than the S2 session alone. This result shows the limits of training focussing solely on general and de-contextualized knowledge on interactions (S2). There is considerable scope for progression if general training and contextualized training in interaction are complementary.

Another result shows that the P3 pupils, whether they fall into the category of high or low achievers, all progress in exactly the same way. The homogeneity in progression, whatever the category of pupils concerned, may be accounted for by the fact that the test deals with pupils' misconceptions on matter. Misconceptions about matter are shared by a large majority of the pupils (Larcher et al., 1990). So it is not surprising then to note that the large majority of these pupils make progress.

The decision for this research to be carried out in actual teaching and training conditions increases the ecological validity of the findings, even if, for this very reason, this choice implies certain limits which need to be taken into account. There is only short-term evaluation of the effects on teachers' practice and pupil learning. A long-term evaluation would make it possible to conclude with more certainty that conceptual change did actually take place. This research does not deal with the impact of the training program on the management of other teaching sessions. We do not know either whether similar results would be obtained with experienced teachers.

This first study could be completed by using a larger number of teachers. Moreover, in a future study, a triple-blind quantitative analysis of the frequency at which negotiation phases occur during the eight sessions could enable us to complete our qualitative analysis. This study would make it possible to carry out a quantitative evaluation of the impact of the training programme on teacher practice. Finally, it still remains to be demonstrated whether this twelve-hour programme can have an impact on teachers beyond teaching just the session on the particulate model. We would indeed like to posit that this programme can have an effect on the way teachers deal with pupils' productions in other teaching contexts, and that it can also make teachers aware of how important it is to gain contextualized professional knowledge in their professional development.

5. Conclusion

The main contribution this research makes is to identify contents in a physics teachers' training programme (how to deal with pupils' explanations during interaction) which impact the teachers' professional practices, which in turn have a proven effect on the quality of pupil learning. The study of literature to be found in the first part of this study has shown that most evaluations of training programmes focus on the teachers (levels 1 and 2) and do not generally consider level 3 (the pupils). Research which only shows the effect of a training programme on teachers is very important, as changing the way one teaches is a necessary condition for pupil learning to progress. The evaluation of the impact of the teachers' training programme on their pupils completes and reinforces the evaluation of the impact of the programme on the teachers themselves. This evaluation also makes it possible to study the impact of certain teaching practices on pupil performance by first triggering and then controlling the change in practices. The results obtained in this research will need to be confirmed by further research based on larger samples. But it does allow us to determine paths for future research.

The findings in this research also provide elements which need further consideration concerning the conditions required for a training programme to be effective. Indeed, the findings show that de-contextualized training has little impact on the way pupils' explanations are dealt with. On the other hand, the findings show a significant change in practices (and a clear progression in pupil achievement) as a result of a training programme aimed at teachers gaining contextualized professional knowledge. The findings of our research seem to indicate that specific and contextualized knowledge is more effective for the construction of effective practice. This finding pertaining to the importance of contextualized professional development resonates with research on teacher pedagogical content knowledge (e.g. Van Driel et al. 2002, International Journal of Science Education 2008).

As far as pupil learning is concerned, the findings of this research indicate a correlation between the implementation of a socio-constructivist approach to dealing with pupils' explanations and an increase in pupils' achievements, whatever their basic academic level. These findings confirm and complete the results obtained in social psychology (Vygotski 1934, Doise et al. 1978, Bruner 1983, Perret-Clermont 1986, Author 2 & Martinot 2004). The findings of this research would also seem to indicate that a training programme focusing on management of interactions in science teaching can have a positive impact on pupil performance.

These initial results open the way for further research, which will aim to assess the impact of this training on the organization of other teaching sessions, and on the professional competences that teachers consider it is necessary to develop in order to teach effectively. The conditions for enhancing this efficiency might also be explored.

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Appendix A: document provided by teachers for pupils during the session

Name Class:

First name

The particulate model of gases

Activity 1: Observations

Observe the experiment carried out by the teacher and then indicate in the table below ‘what has changed’ and ‘what hasn’t changed’ for the syringe and the gas.

<u>Activity 2: Modeling</u>

A gas can be considered as a group of invisible particles which cannot be seen by the naked eye, and which has the following properties:

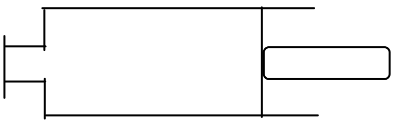
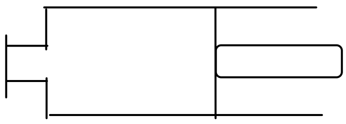
P1 - A particle cannot be cut

P2 - A particle keeps the same size

P3 - A particle keeps the same mass

P4 - A particle cannot change shape

Draw all the gas in situations 1 and 2 to show what you have noticed

 Situation 1	 Situation 2

Activity 3: Conclusion

As a result of the preceding activities, give the meaning of the following expressions

- One single gas = ……………………………………………………………………
- The gas is more compact = ………………………………………………….............
- The gas can be compressed still more =……………………………………………
- There is the same quantity of gas =………………………………………………….

Activity 4: New elements for the model

What else have we learnt in relation to the initial four properties?

…………………………………………………………………………………………………

…………………………………………………………………………………………………

…………………………………………………………………………………………………

…………………………………………………………………………………………………

Appendix B: The questionnaire

Right/Wrong/I don’t know (10 min.)

	Right	Wrong	ID’tK
Gases have mass.			
A gas particle can get bigger.			
The same quantity of gas always has the same volume.			
The same quantity of gas always has the same mass.			
There is air between gas particles.			
There is a void between gas particles.			
If two syringes contain the same number of particles, then they must have the same volume			
If two syringes contain the same number of particles, they must have the same mass			
When I compress a gas, the particles get closer together.			
When I compress a gas, the particles get smaller.			
Two identical footballs are blown up in different ways. The two balls have the same mass.			
Two identical basketballs are blown up in different ways. The number of particles is the same in the two balls.			
Gas can be compressed (its volume can by reduced when it is compressed).			
A gas particle can be compressed (its volume can by reduced when it is compressed).			
If the volume of a gas changes, then its mass must change too.			